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History of cardiopulmonary bypass (CPB)

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The development of cardiopulmonary bypass (CPB), thereby permitting open-heart surgery, is one of the most important advances in medicine in the 20th century. Many currently practicing cardiac anesthesiologists, cardiac surgeons, and perfusionists are unaware of how recently it came into use (60 years) and how much the practice of CPB has changed during its short existence. In this paper, the development of CPB and the many changes and progress that has taken place over this brief period of time, making it a remarkably safe endeavor, are reviewed. The many as yet unresolved questions are also identified, which sets the stage for the other papers in this issue of this journal.

Introduction

The development of cardiopulmonary bypass (CPB) to permit cardiac surgery is considered one of the greatest advances in medicine in the 20th century. Many do not appreciate how recently this has developed. This has occurred during the lifetime of many who are still practicing. The first successful series of open-heart surgery utilizing heart–lung (H–L) machines occurred exactly 60 years ago in the spring and summer of 1955. In this article, the historical development and technological advancement of extracorporeal circulation and CPB are reviewed. Much of this material is based upon or extracted from other publications by this author [1–3], and based upon other papers and books related to the history of cardiac surgery and CPB [4–15]. *Cardiopulmonary Bypass Bibliography,* covering 1667–1989,

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by Utley and colleagues is a particularly valuable resource [16]. Unfortunately, my review has likely overlooked many of the important contributions that have occurred in other countries, if not published in the English language literature.

The birth of use of mechanical H–L machines for CPB in cardiac surgery

The concept of ECC to support organ function was first suggested and explored in animals in the 19th century, but many scientific discoveries and techniques were necessary before clinical CPB could be achieved including blood types and transfusion, heparin and protamine, and the use of silicone antifoam [3,11,17]. A number of surgical teams in the early 1950s attempted to develop H–L machines and used them to perform open-heart surgery without success, but this was finally accomplished by John Gibbon Jr. (Fig. 1A) on 6 May 1953 [18–20]. Dr. Gibbon was inspired to develop an H–L machine while caring for a patient in 1930 as a surgical research fellow. Despite being dissuaded by his mentors, he spent the next 20 years working alongside his wife and finally developed an H–L machine with the assistance of the engineers at IBM (Fig. 1 B and C), with which he achieved 90% survival in dogs. This led to his first clinical application, which failed due to wrong diagnosis, but his second attempt, on an 18-year-old woman with an atrial septal defect (ASD), was successful. Unfortunately, his next two patients, died and he declared a moratorium on further application of his H–L machine. Only one other successful open-heart surgery was performed using an H–L machine during 16 other attempts by six other teams between 1952 and 1954, leading to an attitude of hopelessness. Some hypothesized that human patients, as compared with animal subjects, were too sick to tolerate CPB. However, in March 1954, C. Walton Lillehei (Fig. 2A) and his colleagues at the University of Minnesota initiated a remarkable series of direct-vision intracardiac surgery with total CPB using another adult as the "heart–lung machine" (so-called "controlled cross-circulation"), in which the adult's femoral artery and vein were connected to the child's arterial and venous system, respectively [21] (Fig. 2B). Over the next 16 months, they operated on 45 seriously ill children with congenital heart disease with 28 survivors and thus clearly demonstrated the potential for CPB to permit even complex open-heart surgery in sick patients once a satisfactory artificial H–L machine was available for use by a skillful cardiac surgical team. This was accomplished during the spring and summer of 1955 when two groups, one led by John Kirklin (Fig. 3A) at the Mayo Clinic starting on March 22nd [22] and the other by C. Walton Lillehei (Fig. 2A) starting on May 13th [23], working 90 miles apart, using vastly different H–L machines and approaches to the conduct of CPB, each operated on about 40 cases.

The Mayo Clinic group used the IBM-Gibbon machine, freely provided by Gibbon and IBM, which they modified and called the "Mayo–Gibbon" H–L machine (Fig. 3B). Their H–L machine was capable of oxygenating at flows of 2.4 L/min per square meter, and it included inline arterial and venous saturation and a vaporizer for administering a volatile anesthetic. Lillehei's team employed a helical reservoir bubble oxygenator (BO) (Figs. 2C and D) developed by a young physician, Richard A. DeWall, who was working in the cardiac surgical research laboratory and as a perfusionist for the open-heart cross-circulation procedures.

Lillehei and Kirklin were truly the giants of the development of open-heart surgery, with vastly different styles and personalities. Kirklin was methodical and academic [24], whereas Lillehei was impulsive and action oriented [14], but both made tremendous contributions to the practice of CPB. While searching for a method to conduct open-heart surgery between 1950 and 1955, besides inventing and successfully applying human cross-circulation, Lillehei helped his colleagues at the University of Minnesota develop and apply clinically (but unsuccessfully) an *H–L* machine employing a screen oxygenator and the first successful use of circulatory arrest under moderate surface-induced hypothermia to perform open-heart surgery. He also introduced epicardial pacing to treat surgically induced heart block, and he pioneered the use of median sternotomy and femoral artery cannulation for inflow in the late 1950s. Before it was given a name, Kirklin practiced evidence-based cardiac surgery and perfusion ("show me the data"), stressing the acquisition and the appropriate statistical analysis of objective data. He authored or coauthored many papers, exploring the pathophysiology and optimal conduct of CPB. He was the editor of *The Journal of Thoracic and Cardiovascular Surgery* from 1987 to 1994 [24].